



Properties of particleboard bond with rice bran and polymeric methylene diphenyl diisocyanate adhesives

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Abstract

Rice straw can be used as a fiber source for the manufacture of particleboards. Polymeric methylene diphenyl diisocyanate (PMDI) is widely used as an adhesive for manufacturing such products. PMDI has the ability to bind rice straw despite the wax present on the surface of the straw. Its relatively high cost, petroleum origin, and toxicity in its uncured state are concerns to the rice particleboard industry. A less expensive and environmentally friendly rice bran adhesive may be used to replace a portion of PMDI and still give quality products. The objective of this study was to evaluate the quality of particleboard bond with rice bran based adhesive. In this experiment, rice bran adhesive (RBA) was used to replace 10, 20, and 30% of PMDI adhesive. The properties of the resulting mixed adhesive products were then evaluated and compared with particleboard bond with only PMDI. Up to 30% of the PMDI could be replaced with RBA to yield products with properties similar to those of PMDI bond particleboard.

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1. Introduction

Particleboard and fiberboard in the medium-density range are widely used for construction, furniture, and interior decoration (wall and ceiling paneling). The main lignocellulosic raw material used in the parti-

cleboard and fiberboard industry is wood, but other agro-based residues have not been frequently utilized. Annual plant wastes, such as flax and hemp shives, bagasse, cotton stalks, small grain straw (including rice straw), peanut husks, rice husks, grape stalks, and palm stalks are inexpensive and valuable raw materials for lignocellulosic board production (Kozłowski et al., 1994). The production of panel products from agricultural residues is important considering the increasing worldwide wood fiber shortage.

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The particleboard industry relies extensively on adhesives that account for up to 32% of manufacturing costs in the glued-wood composites industry (Sellers, 2000). At present, particleboard industries depend on synthetic adhesives, such as urea formaldehyde resin, to manufacture panels. About 3.6 Mton formaldehyde-based adhesives are used in the U.S. annually in the construction and furniture industries. Formaldehyde emission is an environmental and health problem in the manufacture, distribution, and application of particleboard (Peng et al., 1997). Adhesives from renewable substances that meet stringent performance requirements and environmental regulations have a huge market potential.

Relatively new synthetic formulations for panel products are the diisocyanate-based adhesives. Advantages of the diisocyanates include their high reactivity, high binding quality for exterior-grade panel products, and no formaldehyde emission. Polymeric methylene diphenyl diisocyanate (PMDI) is of particular interest for rice straw particleboard manufacturing because of its ability to bind rice straw despite the wax present on the surface of the straw. However, the disadvantages of diisocyanates include their relatively higher price and higher toxicity of the uncured glue than other adhesives. Replacing a part or all of the currently used synthetic adhesives with inexpensive and environmentally friendly adhesives is of interest to the particleboard industry.

Among several natural products, high protein containing soybean is finding use in particleboard industry. However, due to its low water resistance and reported low adhesive strength, soy protein-based adhesives have not been accepted in the marketplace (Myers, 1993). Mo et al. (2003) determined that bleached wheat straw particleboard bond with soybean-based adhesive had similar or better mechanical strength than that with urea formaldehyde resins. Alternately, attempts have also been made to use starch-based adhesives in particleboard systems. Peng et al. (1997) found that the properties of particleboard prepared with steam-cooked, starch-based adhesives approached those made with formaldehyde-containing resins.

Rice bran contains starch and protein that may also be used as a bio-based adhesive. Based on our previous results, the overall quality performance of rice bran produced with pH 12 and 100 °C treatment appeared to be acceptable as an adhesive (Pan et al., 2005). The

objectives of this study were (a) to use rice bran adhesive (RBA) to replace part of the PMDI adhesive used to make rice straw based particleboard and (b) to evaluate the properties of particleboards by measuring their mechanical and water absorption properties.

2. Materials and methods

2.1. Materials

Rice straw from a medium grain rice variety M202 was collected in the fall of 2000. It had an average moisture content of 7%. PMDI was obtained from Bayer Polymers LLC (Pittsburgh, PA) and contained 100% solid. Defatted rice bran was obtained from RITO, Inc. (Stuttgart, AR) and contained 3.8% fat, 16.6% protein, 16% starch, and 11.3% ash.

2.2. Rice straw and rice bran adhesive preparation

The size of rice straw was reduced in a mill (Model C269OYB; Franklin Electric Co. Inc., Buffton, IN) using a 1.3 cm screen opening. RBA was made from rice bran treated at pH 12 and 100 °C (Pan et al., 2005). A 20%-milled rice bran solution was prepared with deionized water. The pH of the resulting slurry was adjusted to 12 with 1 M NaOH solution. The slurry was heated in a sterilizer (Model SR-24C; Consolidated Stills & Sterilizers, Boston, MA) to 100 °C and then oven-dried in metal trays at 75 °C for at least 24 h to a moisture content of approximately 10%. The modified dry rice bran was milled for 3 min in a Stein Laboratory Mill (Model M2; The Steinlite Co., Atchison, KS) and sieved through the U.S. #100 mesh screen. A 20% RBA solution was prepared and equilibrated for 1 h to achieve adequate adhesive hydration before it was used for making the particleboard.

2.3. Manufacture of particleboard

Medium density particleboard was fabricated according to the method proposed by Mo et al. (2003). PMDI resins and PMDI resins blended with different amount of RBA were used as adhesives. The adhesives were then mixed with straw using a professional mixer (Model KP2671XBK; KitchenAid, Greenville,

OH) for 15 min. The straw mixture was pre-pressed and further pressed into particleboard on a hot press (Model 3891.4PR1A00; Carver Inc., Wabash, IN) equipped with 22.9 cm × 22.9 cm metal plates. The quantity of straw used was adjusted so that the finished particleboard had a targeted final bulk density of 0.70 g/cm³ and thickness of 0.65 cm. Press conditions for the resinated straw were 1939 kPa at 140 °C for 8 min. The pressed particleboard was then trimmed to avoid edge effects, cut into various sizes for testing, and finally conditioned for at least 48 h in a Fisherbrand® Desiccator Cabinet maintained at a relative humidity of 65% with CoCl₂ solution at 25 °C.

2.4. Particleboard evaluation

2.4.1. Mechanical properties

Particleboards were cut into 3.8 cm × 15.2 cm rectangular sections for determining tensile strength (TS), 17.8 cm × 5.1 cm for static bending, and 5.1 cm × 5.1 cm squares for internal bond (IB) strength measurements. Mechanical properties were determined according to the [ASTM standard method D1037-99 \(1999\)](#) using an Instron testing machine (Model 1122; Instron Corporation, Canton, MA). The crosshead speeds were 4 mm/min for the TS test, and 5 mm/min for the static bending and IB tests. The average modulus of rupture (MOR) and modulus of elasticity (MOE) were obtained in triplicate from the static bending test.

2.4.2. Water absorption and thickness swelling

Water absorption and thickness swell properties were also determined according to the [ASTM standard method D1037-99 \(1999\)](#). For this test, the particleboard was cut into 15.2 cm × 15.2 cm squares and soaked in water at room temperature for 24 h. Board thickness and weight were measured in triplicate before soaking and after 2 and 24 h of water immersion to determine the short-term and long-term water absorption and thickness increase.

2.5. Experimental design and data analysis

A 3 × 3 factorial experimental design was used. For the control, only PMDI resin was added to the straw at 4% resin solid based on the weight of straw. With this PMDI content as a basis, 10, 20, and 30% PMDI

were removed and replaced with 1, 5, or 20 g RBA solids per gram PMDI removed, which corresponded to the replacement ratios of 1, 5, and 20. This yielded three levels of PMDI (3.6, 3.2, and 2.8%) and three levels of RBA (0.4, 4, and 24%) in the particleboards. Therefore, a total of 10 combinations of the adhesives were evaluated in terms of their ability to bind rice straw for particleboard production. To determine the effects of replacing different amounts of PMDI with RBA on the properties of rice straw particleboard, statistical analyses including ANOVA and Tukey's Studentized Range Tests (at 95% confidence level) were performed by means of SAS software (SAS Institute, Raleigh, NC). All boards were fabricated and tested in triplicate.

3. Results and discussion

3.1. Tensile strength

In general, TS decreased as PMDI replacement with RBA increased ([Fig. 1\(a\)](#)). TS decreased from 9.8 MPa for the control to 5.1 MPa for the sample with 10% of PMDI (ratio 20:1) replaced with RBA. As the amount of RBA added to the straw increased, the amount of water absorbed also increased. During hot pressing, this water turned into steam that abruptly expanded when the press was opened. While low amount of steam may not affect particleboard properties, large amount of steam may cause cohesively weak particleboard or may even cause the board to burst. For this reason, it was not possible to obtain high quality particleboard samples for the 20 and 30% (ratio 20:1) PMDI replacement treatments, which corresponded to 50% of moisture content or greater in the particleboard.

No significant difference in TS was present between the control and board manufactured with RBA replacement of the synthetic adhesive at the ratio 1:1. In fact, a 5:1 replacement ratio at the same 30% PMDI removal also resulted in particleboard with TS comparable to the control. Unless higher replacement ratios (i.e., 5:1 or 20:1) yield particleboard with improved properties, it is advantageous to use the minimum amount of RBA that will result in particleboard with properties comparable to the control. Contrary to what was expected, higher replacement ratios (i.e., 5:1 and 20:1), in general, did not prove beneficial. Initially, it was expected

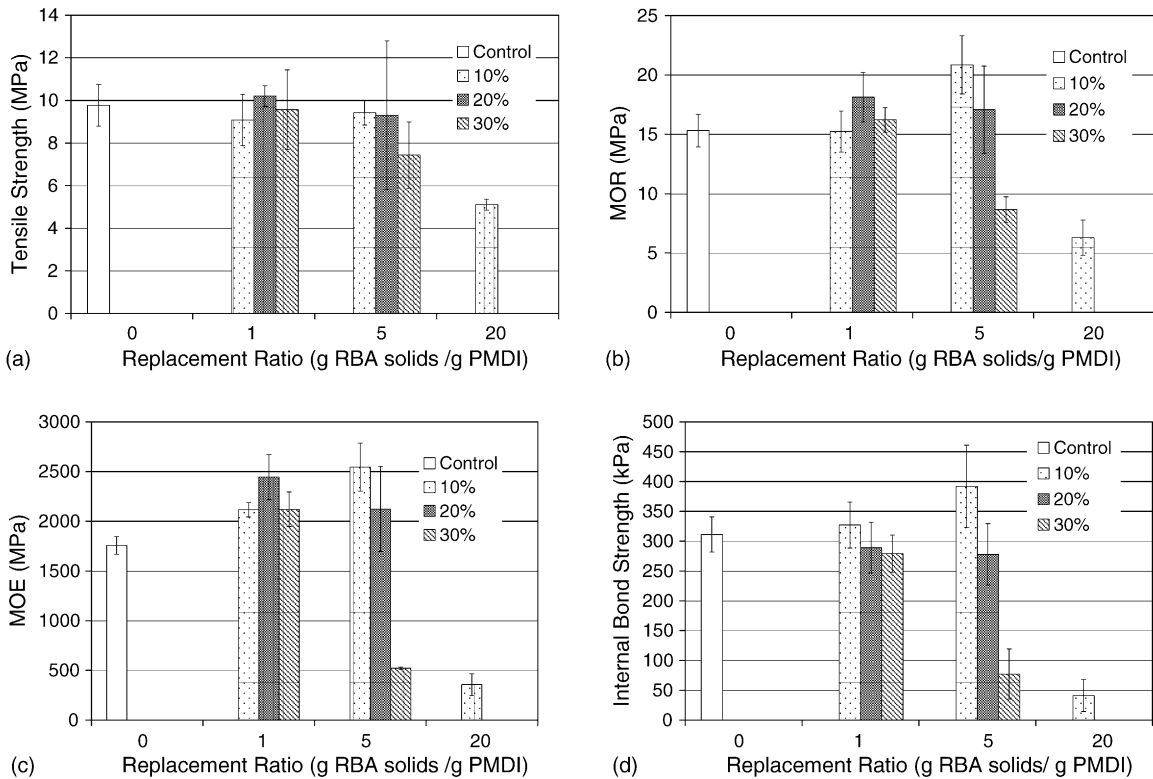


Fig. 1. Mechanical properties of particleboard bond with rice bran adhesive: (a) tensile strength (TS), (b) modulus of rupture (MOR), (c) modulus of elasticity (MOE), and (d) internal bond (IB) strength.

that when more RBA solid was added in the particleboard, the TS of the particleboard should increase. However, because more RBA also meant more water in the mixture of straw and adhesives, the steam during press caused weak binding in the particleboard. In most cases, the 1:1 replacement ratio proved sufficient to obtain a product with properties comparable to the control.

3.2. Static bending: modulus of rupture and modulus of elasticity

The MOR and MOE results obtained from the static bending tests are illustrated in Fig. 1(b and c). The MOR measures the maximum bending load that a board can support. Its value indicates the stress required to cause failure. In general, the MOR values were not significantly different from the control at low PMDI replacement with RBA. The reason for the highest MOR obtained with 10% replacement at the 1:5 ratio could

be due to the increased binding capability of RBA in the particleboard. However, at the high RBA replacement ratio, the MOR was significantly lower than the control. In a similar manner as the tensile strength, up to 30% PMDI replacement with RBA solids (ratio 1:1), the MOR characteristics were the same as the control, which corresponded to about 15% moisture in the particleboard before hot pressing.

The MOE, on the other hand, measures stiffness and indicates the ability to resist deflection. In general, the MOE followed the same trend as the MOR. The MOE decreased at the higher PMDI replacements with RBA and the decrease was more significant at the higher replacement percentages and ratios. Again, a replacement of up to 30% PMDI with RBA resulted in particleboard with a MOE that was not statistically different than the control. It appears from the figure and statistical analysis that a 10% PMDI replacement with RBA gave particleboard with a higher MOE than the control (2545 MPa versus 1758 MPa).

3.3. Internal bond strength

The IB strength decreased as the amount of PMDI replacement with RBA increased except at 1:1 replacement ratio (Fig. 1(d)). This decrease in strength was more drastic at the higher PMDI removal and replacement ratios. For example, the trend can be seen for IB strengths at the replacement ratios of 1:1 and 5:1. As the percentage of PMDI removal increased, IB strength decreased more at the 5:1 than at the 1:1 replacement. Statistical analysis indicated that a replacement of up to 30% PMDI with RBA (1:1 replacement ratio) resulted in a particleboard product with IB strength similar to the control.

3.4. Water absorption and thickness swell

The results obtained for short-term (2 h) and long-term (24 h) water absorption are shown in Fig. 2 (a

and b), respectively. The data show that, as the amount of RBA in particleboard increased, the amount of water absorbed by the board also increased. This result was expected because of the hygroscopic nature of the rice bran adhesive and also the decreased cohesion obtained for particleboard containing the additional water associated with RBA as explained earlier. Low particleboard cohesion could allow water to penetrate readily through the poorly bond board matrix. No significant difference was found between the control and particleboard with up to 30% PMDI replaced with RBA (1:1 replacement ratio) in terms of short-term water absorption. However, only 20% PMDI can be removed and replaced with RBA solids at the ratio of 1:1 to obtain a particleboard product with long-term water absorption properties similar to the control.

The short-term and long-term particleboard thickness swell results had no significant differences between the control and particleboard with up to 30%

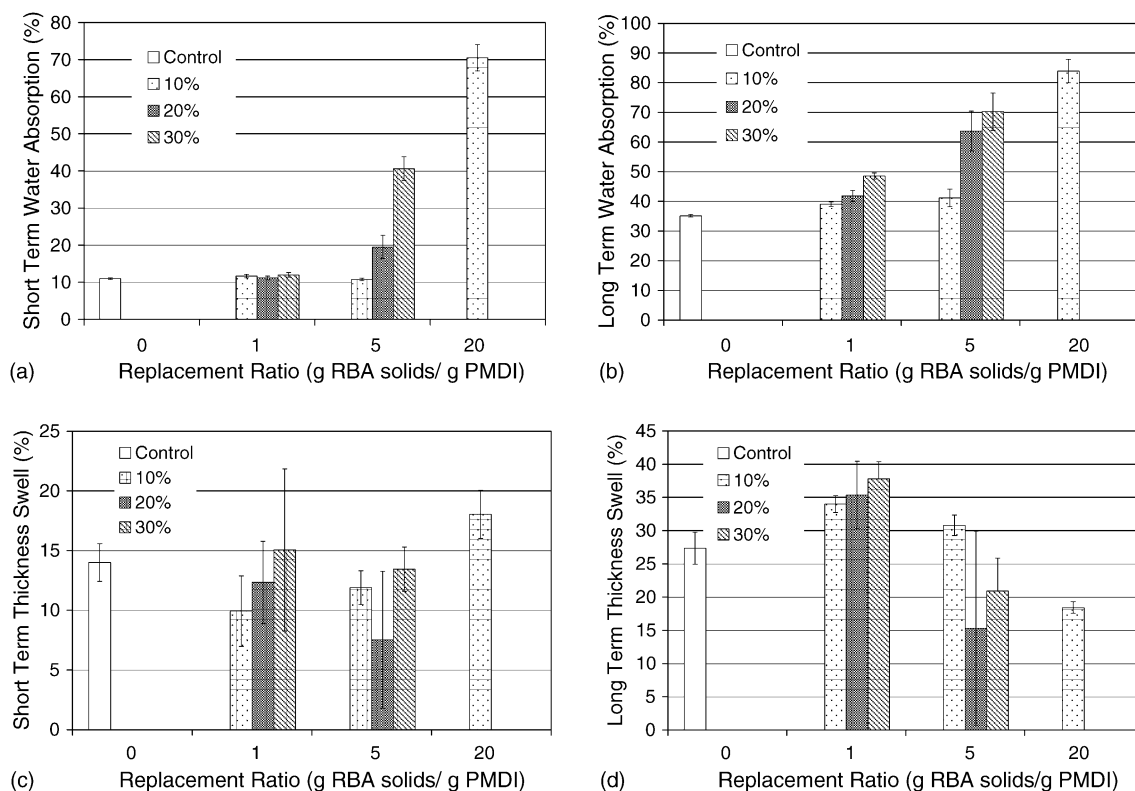


Fig. 2. Water absorption and thickness swell properties of particleboard bond with rice bran adhesive: (a) short-term water absorption, (b) long-term water absorption, (c) short-term thickness swell, and (d) long-term thickness swell.

PMDI removed and replaced with RBA (1:1 replacement ratio) (Fig. 2(c)). The data show a slight increase in thickness swell for both short-term and long-term as the percentage of PMDI replaced with RBA (1:1 replacement ratio) increased from 10 to 30%.

Differences between the short-term and long-term thickness swelling rates of particleboards containing different amounts of RBA were present. After 2 h of water immersion, the particleboard with the 10% PMDI removal had a thickness swell of only 9.9% with 1:1 replacement ratio, but 17% with 20:1 replacement ratio. After 24 h, the thickness swell of sample with 10% and 1:1 placement ratio increased to 34%, whereas the thickness of sample with 10% and 20:1 replacement ratio remained almost the same as the short-term swell at 18%.

4. Conclusion

Rice bran adhesive produced with pH 12 and 100 °C treatment can be used to replace a portion of the synthetic adhesive polymeric methylene diphenyl diisocyanate currently used for the fabrication of rice straw particleboard. Up to 30% PMDI could be replaced with RBA to obtain a product with similar properties as those with PMDI alone. Only 20% PMDI should be replaced with RBA to obtain particleboard with long-term water absorption properties similar to those of the PMDI bond board. Because the RBA used in this study con-

tained only 20% solid, the high replacement percentage or ratio resulted in a particleboard with too high water content to achieve quality products. The application of high solid RBA for manufacturing rice straw particleboard and optimization of the particleboard processing parameters require further investigation.

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